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UNITED STATES AIR FORCE ACADEMY
GET-AWAY-SPECIAL
FLEXIBLE BEAM EXPERIMENT

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OBJECTIVES

The Department of Astronautics at the United States Air Force Academy is currently planning to fly an experiment in a NASA Get-Away-Special (GAS) canister. The experiment has been named the Flex Beam experiment and is being conducted jointly between the Department of Astronautics and Department of Engineering Mechanics. The experiment will allow the Departments to achieve several goals, both scientific and academic.

The primary technical objective of the Flex Beam experiment is to measure the damping of a thin beam in the vacuum and "zero G" environment of space. By measuring the damping in space, we hope to determine the amount of damping the beam normally experiences due to the gravitational forces present on Earth. This will allow us to validate models which predict the dynamics of thin beams in the space environment.

The experiment will also allow the Academy to develop and improve its ability to perform experiments within the confines of a NASA GAS canister. Several experiments, of limited technical difficulty, have been flown by the Academy. More complex experiments are currently planned and we hope to learn techniques with each Space Shuttle flight. Finally, we try to maintain some level of student involvement in our projects. This helps to motivate the cadets to strive for more challenging goals than pure coursework can offer.

- **Measure damping of thin beam in vacuum**

- **Validate models**

- **Develop GAS experiment capabilities**

- **Student involvement**

GAS CANISTER IMPLEMENTATION

We plan to physically implement the flex beam experiment in the GAS canister by using two thin stainless steel beams. One will be used as a control test condition to verify integrity of the data acquisition system. This beam will be put in a cantilever configuration, as the beam's natural frequency should not change in the absence of gravity. The second beam, which is the one of interest, will be put in a pinned-free configuration.

We will be measuring the motion of the beams with strain gauges placed along the beams at the points of maximum expected moment. Strain gauges will also be placed on the shim stock used to create the pinned end so the pendulum mode of the pinned-free beam can be measured.

The beams will be placed within the vacuum of space while the experiment electronics, data recorder, and batteries will be placed within a sealed container and maintained at approximately 1 atmosphere.

- **2 thin stainless steel beams - 2" x 24" x 0.025"**
- **Strain gauges at points of expected maximum moment**
- **Beams in vacuum of space**
- **Controller, recorder, batteries in sealed containers (1 atm)**

BEAM NATURAL FREQUENCIES

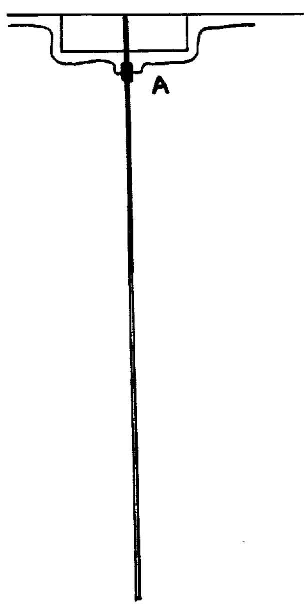
This chart shows the expected results of our experiment. We are planning to fly two stainless steel beams, one in a cantilever orientation and one as a pinned-free orientation. We will not be using a physical pin because of friction, but instead are using thin pieces of shim stock material bonded to the stainless steel beam. The frequency of the cantilever beam should not change based on the absence of gravity. We do, however, expect the frequencies of the pinned-free beam to change as shown on the figure.

Support Condition	Mode	Freq at 1 G	Freq in Space
Cantilever	1 Bend	5.226 Hz	5.226 Hz
	2 Bend	32.75 Hz	32.75 Hz
Pinned Free	Pendulum	0.903 Hz	0.1 Hz
	1 Bend	22.92 Hz	22.92 Hz
	2 Bend	74.26 Hz	74.26 Hz

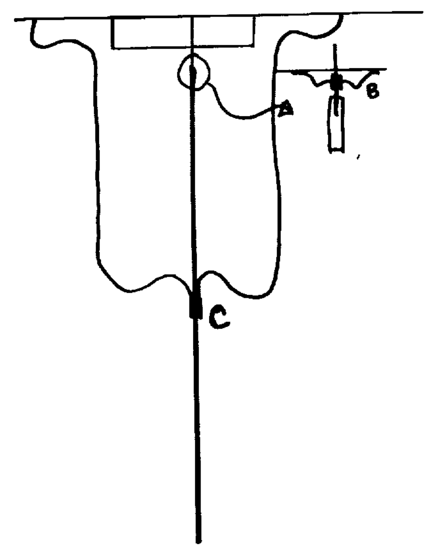
Note: An actual pin is not used due to friction. A thin shim is used instead.

BEAM STRUCTURES

The cantilever and pinned-free beam structures are shown in this chart. Also shown are the strain gauge locations envisioned using the placement method discussed earlier. Strain gauge locations are designated as A, B, or C and will be referred to later in this presentation.



Cantilever



Pinned-Free

ACTUATORS

The purpose of the actuators is to begin the vibration of the beams. Due to space and hardware limitations, we are planning on a maximum deflection of 1 inch. Regardless of the maximum deflection, we are interested in accurately knowing the deflection and being able to consistently repeat the deflection.

Another prime criteria for the actuators, as with all of our hardware, is low power consumption. Part of the problem with our first flight of this experiment was the lack of power once the experiment began operation. Cold soak of the batteries has been determined as the cause of failure with the dampers in the first flight.

- **Begin vibration of beams**
- **Known deflection - maximum of 1"**
- **Repeatable**
- **Low power consumption**

ACTUATOR POSSIBILITIES

Three types of actuators are currently under consideration. The first type we have experimented with is an electromagnet, which was used to pull the beams to start the vibration. This method adequately pulls the beams but we have so far experienced major problems with residual magnetism. This residual significantly affects the motion of the thin beams.

A mechanical striker was used on the first flight of our experiment, but we are not sure that we can implement one which will provide a known, repeatable deflection within the space and budget constraints we have. Another problem with a striker, assuming it operates in an "impulse" input fashion, is synchronization. The pinned-free beam must be deflected at the free end and part way up the beam simultaneously if we wish to achieve a symmetrical input (which we do). Again, our concern is the ability to develop high precision strikers in our budget.

The final option we will investigate is a push-pull rod concept. This would act much as a linear solenoid but must provide the ability to quickly retract the rods to let the vibration begin. This method also has synchronization concerns as well as the potential problem of limited maximum beam displacement.

- **Electromagnets**
  - **Meet objectives**
  - **Residual magnetism problems**
- **Mechanical striker**
  - **Simple to implement**
  - **Synchronization difficulty**
- **"Push-pull" rods**
  - **Space qualified solenoids - cost**
  - **Maximum displacement limited**

DAMPERS

The dampers are used to hold the free end of each beam fixed during all non-experiment times. In addition, they will be used to stop any remaining vibration in the beams between experiment samples.

Like the actuators, low power consumption is a requirement for the dampers. We are searching for on/off dampers which will move when power is applied and hold their position once power is removed. Thus far, the linear solenoids we have tested will not hold their position unless power is continuously applied. This was the cause of failure in our last flight and we are not willing to accept this problem again.

In our search for dampers, we may once again arrive at a "home grown" solution by designing our own mechanisms rather than purchasing something off the shelf. Our other concerns to date have been the cost of vacuum rated solenoids and the limited linear displacement available on the solenoids we have found.

- **Hold free end of beam during non-experiment times**
- **Stop vibrations between experiment samples**
- **Space qualified solenoids**
  - **Cost**
  - **Maximum displacement of 1"**

SEQUENCE OF OPERATIONS

For those not familiar with GAS operations, a brief statement may help. Once NASA has closed the relays, everything else in the experiment must be self contained. This means that the sequence of operations must be programmed to begin once the main power relay is closed.

For our experiment, we will repeat the test 20 times. We have a 45 minute time limit for data recording because of the data recorder we are using. Therefore, we want to allow about 2 minutes of vibration data for each sample, with a total of 20 samples. The remaining 5 minutes will allow 15 seconds for the dampers to close, stop the vibrations, and use the actuators to start the vibrations again.

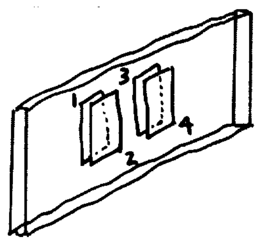
At the end of this sequence the dampers will remain closed, the recorder will shut down, and NASA will open the main power relay to the canister.

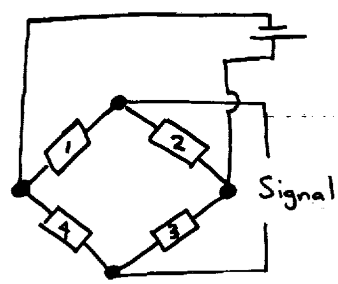
- **NASA relay closed - activate experiment**
- **Start Recorder**
- **Open dampers to release free ends of beams**
- **Activate vibration actuators**
- **Wait 1 minute**
- **Close dampers to stop remaining vibration**
- **Repeat vibration tests for 40 minutes**
- **Stop Recorder**
- **NASA relay opened (experiment shutdown)**

DATA REDUCTION

This chart shows the strain gauge locations planned. By designing the strain gauge circuit in a simplified wheatstone bridge arrangement, we are able to achieve compensation for thermal, axial, and torsional distortions which might otherwise appear in the data. Each strain gauge location planned will actually consist of this bridge arrangement. We will record time histories of the strain at each gauge location by means of an analog data recorder. The expected resolution of the data is 1 microstrain.

Strain Gauge Locations





Simplified Wheatstone Bridge

Compensation Achieved

Thermal
Axial
Torsion

Time histories will be obtained at each strain location
Expected Resolution: 1

RESOLUTION

This chart indicates the peak moment, peak strain, and percent of resolution available for strain location. The information is broken out by beam type, strain location, and vibration mode.

Cantilever Beam

Mode	Location	Peak Moment	Peak Strain*
1 Bend	A	5.713 in-lb	76.2
2 Bend	A	1.07 in-lb	14.3

Pinned-Free Beam

Mode	Location	Peak Moment	Peak Strain*
Pendulum	B	0.013 in-lb	207.9
1 Bend	B	0.051 in-lb	817
1 Bend	C	18.54 in-lb	247.5

* Values are in microstrains

VACUUM OPERATIONS

The requirements we face for operating part of our GAS canister experiment in a vacuum are indicated here. Most of these are expected kinds of requirements, but all of them are new for our department because of the limited experience we have with hardware in space. Much of our time is being spent searching our suppliers for the equipment. Another block of time is being spent and will be spent learning just what these requirements translate to in terms of actual hardware. These difficulties are the price we pay to become experienced in space operations and we expect this Flex Beam experiment to teach us a lot about GAS canister experiment design as well.

- **Space Qualified Parts**
  - **Electrical Connectors**
  - **Solenoids and Acuators**

- **Maintain Pressure for Electronics**
  - **Sequencer / Controller**
  - **Analog Tape Recorder**
  - **Power Supply**

- **Difficulties**
  - **Source for solenoids and actuators**
  - **Material selection: gaskets, glue**

PRE-FLIGHT TESTING

All good scientific experiments involve large amounts of testing, some with actual hardware, some with simulation. We plan to perform extensive hardware testing prior to turning our experiment over to NASA for flight. We want to insure our hardware is reliable, our expected results are reasonable, and our reason for space flight is valid.

The tests are aimed at determining the amount of atmospheric damping present at various atmospheric pressures. To accomplish this, we will test the system at a constant temperature with various atmospheric pressures. Testing will also be done to determine any temperature dependent damping the stainless steel beams may possess. Testing at cold temperatures will also provide important reliability information about our experiment hardware.

Test Description	Objective
Ground Test - 1 Atmosphere	**System Checkout - Benchmark**
Ground Test -	
Reduced pressures to near vacuum (constant Temp)	**Pendulum mode - Damping vs Air Pressure**
Reduced temperatures to -35 C (constant pressure)	**Damping vs Temperature**

SCHEDULE MILESTONES

The schedule for this experiment is shown below. If the actuator and damper mechanisms are determined by March 1989, hardware assembly should be complete by May or June 1989. This is only possible if we locate readily available off the shelf equipment. Hermetic electrical connectors currently look like the problem area in terms of cost and availability.

The schedule allows for testing throughout the summer with data reduction following. Once we are convinced of the validity of our test data and rationale for flight, we will inform NASA that we are ready for launch. From that time on, it becomes a waiting game.

June 1989	**Hardware Assembly Complete**
September 1989	**Pre-Flight Testing Complete**
October 1989	**Test Analysis Complete**
?????	**Shuttle Flight**
??? + 2 months	**Flight Data Analysis Complete**
??? + 3 months	**Report Complete and Available**

FOLLOW-ON RESEARCH

The Departments of Engineering Mechanics and Astronautics are currently working together on a six-foot hanging beam experiment. Some of the experiment goals deal with validating predicted modes of vibration and examining the effects of actuator placement on the beam's dynamics. These will both be accomplished using simple open loop configurations.

The goals also include closing the loop on the actuators and validating the closed loop performance of the vibrating beam with the pendulum mode involved (since the beam is under the gravitational attraction of Earth). The experimenters would then like to project what closed loop performance might be achieved when the pendulum mode is not present, as in space.

Finally, we hope to eventually develop a GAS canister implementation of this experiment with actuators operating in closed loop to try and verify the earlier projections.

Six - foot Hanging Beam Experiment

- **Open Loop**
  - **Validate Predicted Modes (including Pendulum)**
  - **Examine Effects of Actuator Placement onDynamics**
- **Closed Loop**
  - **Validate Closed Loop Performance with Pendulum Mode**
  - **Project Closed Loop Performance without Pendulum Mode**
- **Develop GAS canister implementation of experiment**